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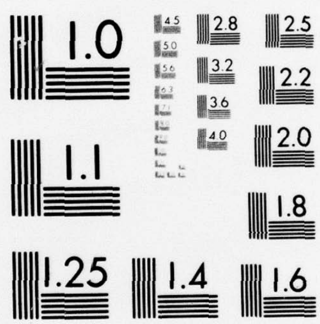
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IS THERE A COST PRICE FOR THE HEAT PRODUCED FROM ELECTRONUCLEAR POWER STATIONS?

IS THERMODYNAMIC EQUIVALENCE AN ECONOMIC TRAP?

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The thermodynamic equivalence between heat and electricity, when used uncritically and carelessly translated into a price equivalence, can effectively hide a very formidable economic "trap" and the advantage it appears to indicate for heat production at relatively low temperatures is to be distrusted; in many cases, this advantage may be of little importance in comparison with the disadvantages of low temperatures for transportation and storage.

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IS THERE A COST PRICE FOR THE HEAT PRODUCED FROM ELECTRONUCLEAR POWER STATIONS? IS THERMODYNAMIC EQUIVALENCE AN ECONOMIC TRAP?

The increase in the price of fossile fuels, especially oil, has revived interest in the mixed or integrated processes for the simultaneous production of heat and electricity, applying the principal of "total energy." These procedures, which are used in industry and in urban heating, especially abroad, make it possible to obtain mechanical energy (or, more frequently, electrical energy) and heat with a lower fuel consumption than in separate processes.

The best-known example is that of the counterpressure turbine, which produces electricity by "spinning" steam until it reaches a temperature and pressure at which the steam is still usable for thermal purposes, especially to provide heat to a heating system either directly, if it is a steam heating system, or by condensation if it is a hot-water or superheated-water system. This solution makes it possible to use completely the energy contained in the fuel, either in the form of electricity or in the form of heat, and its "overall thermodynamic efficiency" can theoretically reach unity, which makes it possible to speak of "total energy" and in a sense to circumvent Carnot's principle.

However, this system has the disadvantage of setting up a rigid connection between the production of electricity and the production of heat: these outputs are necessarily simultaneous and are proportional in theory and in practice also, for the possibilities of manipulating the output temperature of the turbine are strictly limited by the nature of its construction.

One can also resort to extraction turbines in which, on the contrary, the production of electricity and the production of heat can be substituted for each other, within certain limits imposed by the design; there is never more than partial substitution of heat for the production of electricity.

In either of these systems, there is an equivalence ratio between the quantity of heat produced and the electrical energy that was lost in order to produce it. This equivalence ratio is higher when the temperature at which the heat is produced is lower, and also when more elaborate systems are used. (For example, this ratio is improved in extraction turbines by using staggered extractions, staged at several points of the steam relaxation cycle, instead of a single extraction.) This ratio is limited by Carnot's principle at each temperature

at which heat is extracted. In the limit, in a power station designed purely for the production of electricity, the very large quantity of heat that is inevitably wasted as a result of this design (and which in some power stations frequently represents up to 65 percent of the heat provided by the fossile fuel or the nuclear reaction) is available without any loss in the production of electricity: the heat/electricity ratio is therefore infinitely large. Unfortunately this heat, at a temperature of 30 to 35 °C, cannot in the first place be transported under technically and economically reasonable conditions, and therefore must necessarily be used on the spot; and in the second place, its uses are very limited (soil heating, warm irrigation, greenhouse heating, and, under certain conditions, the raising of aquatic plants and fish). Nevertheless it is these useless quantities of heat, improperly audited by those used to adding dish-cloths and towels, that have given rise to the ridiculous myth of the calories lost in electricity-producing power stations, especially electronuclear power stations, that periodically revives in the press, unfortunately sometimes even over the signature and with the guarantee of authors boasting scientific degrees. In fact, heat has more uses and is less expensive to transport when its temperature is higher: the cost of heat should never be given without specifying the temperature at which it is provided. Calories at 30 °C, at 80 °C, at 140 °C, and at 180 °C are in fact four kinds of merchandise with completely different utility and value; the value can even become negative, for example, when we are talking about useless heat at 30 °C which it is necessary and even expensive to dispose of.

The existence of this thermodynamic equivalence between the lost production of electricity and the heat obtained in exchange has led some people to fix the cost price of heat in terms of that of electricity: since N kilowatt-hours were lost to produce one thermal unit, the cost price of the thermal unit is that of N kilowatt-hours. This apparently simple argument is actually too simple, and can become dangerous.

On the one hand, it does not take into account the specific technical modifications or additions necessary for the production of heat, whose amortization must obviously be covered by the sale of the heat and not borne by the consumer of electricity. But on the other hand, and more importantly, /this argument implicitly assumes that the producer of electricity has at all times the choice between producing electricity and producing its equivalent in heat/. But this is not generally, and even almost never, the case, especially in France.

First of all, it is not the case if there is a rigid connection between the production of heat and that of electricity. This is what occurs with the counterpressure turbine, a purely theoretical case since the unit power of reactors cannot be adapted to coupling with such a turbine of comparable power: such a turbine, fed by a 3000 thermal MW reactor, would provide more than 2000 thermal MW.

In conjunction with seasonal heat storage, such an installation alone could provide around 12 to 15 billion thermal units, which is the annual consumption of more than a million housing units, or the consumption for domestic heating of a city of 3 to 4 million inhabitants. The distribution system necessary to make use of this production would require an investment of 8 to 10 billion francs,

five to six times the cost of the power station itself, and at least two years of work by the entire department of mains of the French public works industry. These estimates demonstrate the difficulties of coordinating such a gigantic operation, which could be set up in only a few places in the world.

Without seasonal heat storage, such an installation can supply around 400,000 housing units (1,500,000 inhabitants) with 50 percent of their maxiumum demand; but considering the inflexibility of the design, two-thirds of the heat, especially that produced in the summer, will not be bought and must be expelled into the environment.[1] The result is an increase in thermal pollution in the summer, when it is really dangerous[2], greater than that of a purely electricity-producing nuclear power station using the same pile and producing 10 to 20 percent more electricity.

These obvious disadvantages make it impossible to adapt electronuclear power stations to rigid solutions on such a large scale, and show that the principle of counterpressure must be reserved for partial solutions, like the following.

Part of the live steam produced by a reactor and normally feeding a classical turboalternator can be diverted for the mixed production of heat and electricity by an auxiliary counterpressure turbine. By this subterfuge one regains a certain elasticity in the/technical/capability of substituting one type of production for the other, by modifying the amount of steam diverted.

This same technical capability also exists within certain limits for the turbines, by the practice of extracting steam at different points in the relaxation cycle. The turbines must of course be designed for this purpose.

But the obstacle is not necessarily technical. It can be economic or legal. This is especially the case for a licensed producer of electricity whose contract requires him to meet the demand for electricity: his choice is no longer free, and he can no longer change from the production of electricity to the equivalent production of heat. Even if this is technically possible, the interconnection of the systems generally requires the production of electricity to be switched over to another power station, whose unit cost would be different -- for example, a solid-fuel power station. Then the /thermodynamic equivalence/ does indeed mean an /economic equivalence in price/, but this equivalence is based on the cost of electricity produced /by the other power station/.

Thus a cost price for heat cannot be fixed without taking into account the technical capabilities of the producer of electricity, and especially those resulting from interconnection and from the legal obligations to which he is contractually bound with respect to his clients. Thus different production costs cannot in general be given for different types of power station -- for example, for different nuclear models. As soon as there is interconnection, there is cost alinement, unfortunately at the level of the highest costs.

The problem becomes even more complicated when one turns to production systems that do not permit, or only partially permit, the substitution of one type of production for the other during a run, but in which a production substitution

is the result of irreversible technical arrangements made at the time of the initial project. One is then back in the classical case of the simultaneous production of several products by a single process; this is, for example, the case with petroleum refineries. In such a case there is indeed an overall cost price; but dividing it up into the individual cost price for each product necessarily introduces considerations which are, if not arbitrary, at least non-technical, and this division is not independent of the sales possibilities of each product. If at certain times the production of electricity entails the parallel production of a certain quantity of heat that can neither be sold nor stored, the value of that heat can only be taken as /zero/ -- or even /negative/, if it cannot be disposed of without cost.

Heat storage increases the complexity of the problem still further. The timetable for heat production is then disconnected from the timetable for consumption. The producer thus has the capability of choosing the timetable, and the heat produced can be the equivalent of "slack time" electrical energy, which has a lower value.

The impossibility of storing electrical energy results in the fact that the kilowatt-hour is, from the economic point of view, not a truly fungible product. In fact, its value varies from hour to hour and from season to season. Economically speaking, there are as many different kilowatt-hours as there are time periods distinguishing different demand situations, which are translated in a simplified fashion into different rates.

With seasonal heat storage, it is even possible for heat to be produced as a substitute for electrical energy which it would be technically possible to produce, but for which there is no demand at all. The cost of the heat, in that case, is only the cost of the fuel used to produce it. This can be extremely low if nuclear fuel is used. Thus we see that the mean cost of heat can be a decreasing function of the proportion of nuclear equipment used in the thermal production of electricity.

The net cost of the heat produced by electronuclear power stations thus depends, in the final analysis, on many factors: the demand of the two groups of customers, those buying electricity and those buying heat; the technical capability of choosing the type of production; legal obligations; storage facilities; storage techniques (daily or seasonal storage); location of the power station in a general, interconnected electrical system; composition of the set of power stations making up this system; and the extent to which nuclear equipment is used in the system.

Thus we see that it is impossible to set a cost price for heat by means of a simple argument that does not take all these data into account, and that in fact there are as many prices as there are objective situations; and nothing changes with time faster than these prices.

It is not even possible to give the trend of the net cost as a function of the temperature of production. The classical thermodynamic equivalence in total energy processes, whose translation into an economic equivalence would indicate

a large decrease in the cost of heat with decreasing temperature, is more often than not a trap, even from this point of view. Apart from the necessity of using the sale of heat to amortize the cost of the specific auxiliary equipment or the increased costs resulting from the modifications necessary to produce heat, it must be pointed out that the effect of size on the investment cost of nuclear power stations leads to reactors of high unit power: the installation of even limited equipment for heat production implies a large unit production and therefore an extensive delivery system. Transportation and, possibly, storage costs then become the predominant factors in the cost of the heat provided to the customers. But these costs decrease as the temperature of the heat increases. In the final analysis, the number of customers who can be reached increases with the temperature. The amortization of the specialized equipment is facilitated in this way, and above all the use of relatively high temperatures is often the only way of increasing the number of customers for heat up to the capacity of the power stations.

Here again, heat storage can have a very important effect. In fact, it makes it possible to distribute heat obtained in exchange for very low-cost kilowatt-hours -- even cost-free, since there is no demand for them (or, to be exact, at a marginal cost restricted to the cost of the nuclear fuel necessary to produce them). To be sure , a thermal unit[3] at 180 °C can be obtained in exchange for 1/4 to 1/5 Kwh (depending on the degree of sophistication of the process used)[4], while a thermal unit at 95 °C can be obtained in exchange for 1/8 to 1/10 Kwh.

But when the Kwh of electricity in question is marginal and can be reckoned at the price of the fuel necessary for its production alone -- that is, about 1.5 centimes -- it makes little difference whether this low cost is divided by 4 to obtain a thermal unit at 0.4 centimes, or by 8 to obtain one at 0.2 centimes. In any case, a gain of 0.2 centimes is of no interest at all[5], since it will be immediately lost on account of the increased unit cost of transportation and storage, and may even be less than the effect of the amortization of the more complicated and expensive specialized equipment required by heat production at a lower temperature. One cannot use the same argument for nuclear kilowatt-hours, for which the nuclear fuel represents only a minor part of the cost, as is used for kilowatt-hours produced by fuel oil or coal, where the fuel represents by far the major factor in the cost. This explains why, in dealing with nuclear power, thermodynamic equivalence can become a real "trap" if it is translated carelessly into economic equivalence.

To be fascinated with thermodynamic equivalence and to use a criterion applicable to expensive fuels in a nuclear argument, can lead to monumental economic mistakes.

The conclusion to be drawn from these considerations is finally very simple.

There is no one cost price for the heat produced by electronuclear power stations, but a large number of cost prices which vary widely with the circumstances and are very changeable with time.

The thermodynamic equivalence between heat and electricity, when used uncritically and carelessly translated into a price equivalence, can effectively hide a very

formidable economic "trap," and the advantage it appears to indicate for heat production at relatively low temperatures is to be distrusted: in many cases, this advantage may be of little importance in comparison with the disadvantages of low temperatures for transportation and storage.

FOOTNOTES

1. Unless, of course, the production of electricity is adapted to the production of heat -- that is, operating only 4000 hours per year, which is economically disastrous.

2. For in winter, thermal pollution is generally not pollution, and can sometimes even be a benefit.

3. 1000 thermal units = 1 Gcal; 1 thermal unit = 1.16 thermal Kwh.

4. 1/3 Kwh by direct extraction of live steam, without the use of a turbine.

5. It is sufficient to compare it with the cost of the delivered thermal unit. In order to be competitive with the thermal unit produced by fuel on the spot, it is good enough to be lower than 6 centimes, or 30 times more.